Operant Control of Alpha EEG and the Effects of Illumination and Eye Closure

JEFFREY R. CRAM, ROBERT J. KOHLENBERG, PHD,
AND MICHAEL SINGER, PHD

The effects of eyelid position (open or closed) and three levels of room illumination on operant control of alpha EEG were investigated utilizing a factorial design. After base-line levels were determined, subjects were given alpha-contingent feedback and instructed to increase and decrease alpha production during six successive 4-min intervals. In addition, a comparison was made between percent time and average amplitude as dependent measures. The percent time data indicated that eyes-open training facilitated alpha enhancement and suppression. However, this was not supported by the average amplitude data. Ambient illumination, regardless of the measure utilized, facilitated alpha training, particularly when the eyes were open. These results are related to previous research and theoretical issues.

INTRODUCTION

The operant control of occipital alpha has been demonstrated by several researchers. Utilizing within subject comparisons, Kamiya (1) and Nowlis and Kamiya (2) were able to show significant differences between alpha enhancement trials and alpha suppression trials. Between group comparisons have demonstrated significant differences between a contingent feedback group and yoked controls (3). Black (4) has argued that it is now time to investigate procedural manipulations that might facilitate or hinder the operant conditioning of neural events. Many investigators have turned their attention to such a task. The effects of subjects' expectations of learning to enhance their alpha production and its effect upon subsequent training has been investigated by Valle and Levine (5). Walsh (6) has investigated the effects of instructional set on the subject's subjective experience of the alpha state. Monetary rewards contingent upon performance have been used by Kondo et al. (7) to investigate the role of subject motivation in learning to enhance alpha production.

The effects of various types of feedback have also been investigated. Kuhlman and Klieger (8) investigated the effect of having the binary feedback signal contingent upon alpha production or non-alpha production. Their research suggests that the feedback tone may have unconditioned inhibitory factors that may lead to the suppression of spontaneous alpha. Different types of auditory feedback (analogue versus binary) were investigated by Travis et al. (3), in which they found that analogue feedback was most effective for training when the subject's eyes were closed, while binary feedback was most effective when the subject's eyes were open.

The present study is concerned with the effects of illumination levels of the experimental chamber and the position of the subject's eyelids (open or closed) on a

From the Department of Psychology NI-15, University of Washington, Seattle, Washington 98195.
Received for publication October 28, 1975; final revision received August 23, 1976

subject's ability to learn to control his alpha production. Previous research by Paskewitz and Orne (9) has indicated that a subject's ability to enhance his /her alpha production may be limited if a source of illumination is not present in the experimental chamber. This led them to the conclusion that "subjects can acquire volitional control over alpha density only under conditions which normally lead to decreased densities." Clearly, their data indicate the importance of illumination levels, and yet this variable seems to have been largely neglected. Most investigators either do not report illumination levels or refer to them vaguely as "ambient." In order to investigate more precisely the nature of the relationship between illumination and alpha training, it would be necessary to test at least three levels of illumination.

There is a paucity of research involving systematic investigations of the effect of instructing subjects to keep their eyes open or closed during the experiment. Walsh (6) systematically varied eyelid position and reported reliable results, but did not describe the nature of the effect. A study by Travis et al. (3) indicated that alpha enhancement due to training was significantly greater when the eyes were kept open as compared to when the eyes were kept closed. Many investigators (9–11) have suggested that visual stimulation, occular movement, focus, and accommodation may affect alpha producion. This being the case, the subject may utilize these cues when learning to enhance alpha production with his eyes open.

The present study, employing a factorial design, was aimed at providing information about the effects of eyelid position and illumination levels on the operant control of occipital alpha. In addition, a comparison was made of two methods of measuring alpha: the percent time above threshold and "integrated alpha" or "average amplitude."

METHOD

Subjects

Forty-eight male undergraduates from the University of Washington voluntarily participated in the study. The data from six of these subjects were not used because their resting baseline showed no discernible alpha.

Apparatus

A J and J EEG amplifier and bandpass filter (3 db at 8-12 Hz), model M 50, was used. The filtered and amplified signal was integrated (5-sec time constant) and recorded on a Narco Physiograph, model DMP-4A, and a J & J Digital Scorekeeper, model LGS #100. The Scorekeeper controlled the feedback and digitally displayed the percent time above threshold, averaged over 1 min. Feedback was in the form of a soft white noise. Room illumination levels were controlled by a calibrated Variac. An SEI Meter was used to determine the average level of room illumination. Three levels of illumination was calibrated: bright, 1.4 log ft lamberts; ambient, 0.4 log ft lamberts; dark, 0 log ft lamberts. The apparatus was located in a control room that was adjacent to the experimental room.

Design

There were six experimental groups of seven subjects each. A 3 × 2 factorial design was used, which consisted of three levels of illumination, dark, ambient, and bright, and two levels of eyelid position, open and closed. It should be noted that the above illumination levels and eye position are those that occurred during the training phase of the experiment. These variables were also manipulated during the base-line phase, and this will be described later. The groups were trained under the following conditions: Group 1, eyes open—dark; Group 2, eyes open—ambient; Group 3, eyes open—bright; Group 4, eyes closed—dark; Group 5, eyes closed—ambient; Group 6, eyes closed—bright.

Procedure

The subject was comfortably seated in the experimental room. While the electrodes were being applied to O_2, T_6, and a forehead ground, a 3 × 5 card was given to the subject. The card read either "eyes open" or "eyes closed," and the subject was informed that the meaning of the card would become clear when he heard the instructions for the experiment, which were to be presented over a set of headphones. The subject was also informed that the illumination of the room might change over the course of the experiment. The experimenter then left the room, and the instructions were presented. The initial instructions included an explanation of the nature of biofeedback and that at a later point in the experiment a white noise would be presented whenever the "desired brain waves occurred." Subjects were also told that they would be asked to turn on and to turn off the feedback at various times. The sequence of the experiment was then described to the subject and he was asked to keep body movement to a minumum and to avoid drowsiness.

The experiment consisted of three main parts: the first was the base-line period, the second was the threshold adjustment period, and the third was a series of "on"/"off" or training periods.

Base-Line Period. The base-line period consisted of two 4-min intervals. The first base-line interval consisted of 2 min eyes open, 2 min eyes closed in an ambient illumination. The second base-line interval consisted of 2 min eyes open, 2 min eyes closed in the illumination appropriate for the condition the subject was to be trained in. Instructions were given between each of the 2-min intervals, so that the subject would put his eyelids in the desired position. At the end of the base-line recordings, the subject was instructed to keep his eyes in the condition stated on the 3 × 5 card for the duration of the experiment. One-half of the subjects had cards with "eyes open" written on them, whereas the remaining 50% had 'eyes closed." The illumination levels for the experimental groups were also maintained for the duration of the experiment, including the threshold adjustment period.

Threshold Adjustment Period. The base-line period was followed by a 4-min threshold adjustment period. The subjects were instructed to relax and to become comfortable while some minor adjustments were made on the equipment. During this period, threshold values were adjusted so that the subject's percent time above threshold scores were within the 25% to 35% range. Once this threshold value was established, it was maintained for the duration of the experiment.

On/Off Periods. During this phase of the experiment, the subject was presented with a soft white noise whenever filtered EEG activity surpassed the threshold value. All subjects were requested to increase the amount of time that white noise was presented during the "on" periods and to decrease the amount of time that the white noise was present during the "off" periods. The former represented attempts at alpha enhancement while the latter represented attempts at alpha inhibition. The instructions to the subject followed this sequence: the subject was instructed to "keep the white noise on," and a 4-min trial was initiated. This was followed by instructions to "rest," and a 1-min period (no feedback) followed. Then the subject was instructed to "keep the white noise off," and a 4-min trial was initiated. This was followed by a 1-min rest period, 4 min of keeping the white noise "on," a 1-min rest period, 4 min of keeping the white noise "off," and so forth until the subject had completed three "on" periods and three "off" periods.

RESULTS

Two measures of alpha activity were obtained. The first, average amplitude, was the mean peak-to-peak amplitude in microvolts. Means were determined by measuring 1-min segments of the physiograph record, determining the average microvolt output for that minute, and then averaging the minute samples for a given condition. Artifacts due to "gross" EMG activity were eliminated from these calculations. Because of frequent movement artifacts during the rest periods, these periods were not analyzed. The second measure, percent time, was the mean percentage of the time that the amplitude of 8-12-hz activity exceeded the individual subject's threshold. These means were computed by averaging the minute samples for a given condition as in the first measure.

Baseline

The average amplitude of filtered EEG activity during the four base-line periods is given in Table 1. An ANOVA on these

TABLE 1. Average Amplitude of 8-12-Hz Activity during Two Base-Line Periods for Each of the Six Experimental Groups While Eyes Are Open and Closed and under Ambient and Test Illuminations

Group	Baseline One: ambient illumination[a]	Eyelid position Open	Eyelid position Closed	Baseline Two: test illumination[a]	Eyelid position Open	Eyelid position Closed
1	A	8.44	15.54	D	10.39	12.29
2	A	8.59	14.13	A	8.10	14.00
3	A	10.30	18.13	B	10.42	16.81
4	A	8.30	12.62	D	9.29	12.23
5	A	6.90	11.04	A	6.84	9.69
6	A	10.20	10.69	B	8.82	10.36
Mean [in microvolts (peak-to-peak)]		8.74	13.69		8.97	12.56

[a] D = no illumination (dark); A = ambient illumination; B = bright illumination.

data indicated that alpha production was significantly enhanced when the subjects' eyes were closed ($F = 36.83$; $df = 1, 36$; $P \leq 0.005$). It was also indicated that there were no group differences during the base-line period. There was a significant interaction, however, between eyes open or eyes closed and the first and second base-line period ($F = 5.02$; $df = 1, 36$; $P \leq 0.05$). This interaction resulted from the eyes-closed condition during the second base-line interval ($\overline{X} = 12.57$) producing significantly lower amplitudes in the 8–12-Hz range than that of the eyes-closed condition during the first base-line interval ($\overline{X} = 13.69$).

TABLE 2. Average Amplitude (8-12-Hz Activity) during Base-Line[a] and Off Periods

Group (condition)[b]	Baseline	On period	Off period	Difference
1. (EO/D)	10.39	10.50	9.87	0.63
2. (EO/A)	8.10	10.54	7.40	3.14
3. (EO/B)	10.42	11.64	9.74	1.90
4. (EC/D)	12.23	11.34	10.91	0.43
5. (EC/A)	9.69	9.87	8.26	1.61
6. (EC/B)	10.36	10.93	10.14	0.79

In microvolts (peak-to-peak).

[a] Base-line measures taken under test illumination and eyelid position.

[b] EO = eyes open; EC = eyes closed; D = no illumination (dark); A = ambient illumination; B = bright illumination.

The "On" and "Off" Periods

The means during the "on" and "off" periods for average amplitude and percent time data are shown in Tables 2 and 3. An ANOVA with repeated measures (for the on/off periods) indicated a significant repeated measures effect for both the percent time and average amplitude measures ($F = 32.43$; $df = 1,36$; $P \leq 0.001$; $F = 24.50$; $df = 1,36$; $P \leq 0.001$). The eyelid position times on/off periods interaction was significant *only* for the percent time measure

TABLE 3. Percent Time above Threshold during On and Off Periods

Group (condition)[a]	On period	Off period	Difference
1. (EO/D)	52.26	48.54	3.72
2. (EO/A)	72.93	22.77	50.16
3. (EO/B)	43.77	25.93	17.84
4. (EC/D)	41.24	32.64	9.60
5. (EC/A)	57.21	39.20	18.01
6. (EC/B)	43.79	37.61	6.18

[a] EO = eyes open; EC = eyes closed; D = no illumination (dark); A = ambient illumination; B = bright illumination.

($F = 4.50$; $df = 1,36$; $P \leq 0.05$), while the illumination levels times on/off periods interaction was significant for *both* the percent time and average amplitude measures ($F = 7.73$; $df = 2,36$; $P \leq 0.01$; $F = 3.46$; $df = 2,36$; $P \leq 0.05$).

A Duncan's Multiple Range Test was computed for the three significant interactions. The percent time measure indicated a significant difference between the "on" and "off" period for both the eyes-open condition ($P \leq 0.01$) and the eyes-closed condition ($P \leq 0.05$). In addition, the "on" period was significantly greater for the eyes-open condition when compared to the eyes-closed condition ($P \leq 0.05$) as shown in Fig. 1. It should be noted, however, that none of these comparisons were significant for the average amplitude data, as can be seen in Fig. 2. Under ambient illumination, significant differences were found between the "on" and "off" periods for both the percent time and average amplitude measures ($P \leq 0.01$). Under bright illumination, *only* the percent time measure indicated a significant difference between "on" and "off" periods ($P \leq 0.05$). There were no significant differences between "on" and "off" periods for the dark condition. During the "on" period, the percent time measure was significantly greater for the ambient condition when compared to either the dark or bright conditions ($P \leq 0.01$). No significant differences emerged during the "off" period for this measure, as shown in Fig. 3. The average amplitude measure indicated no significant differences during the "on" periods, with the ambient condition being significantly lower than either the dark and bright condition during the "off" period ($P \leq 0.01$). This can be seen in Fig. 4.

It should be noted that the only Duncan's comparison that was significant for both percent time and average amplitude measures was the on/off comparison under ambient illumination. Further examination of these data (pairwise comparisons were made on all of the six group means using Schefe's test) indicated that only Group 2 (eyes open/ambient illumination) showed a significant difference between "on" and "off" periods. This was true for both the percent time and average amplitude measures ($F = 44.9$; $df = 6, 36$; $P \leq 0.001$); $F = 20.3$; $df = 6, 36$; P

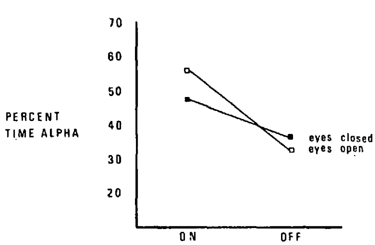

Fig. 1. The interaction between eyelid position and on/off periods.

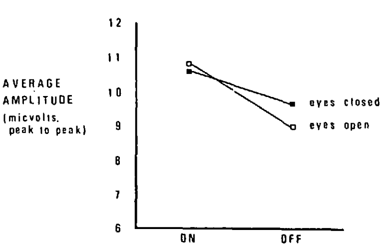

Fig. 2. The interaction between eyelid position and on/off periods.

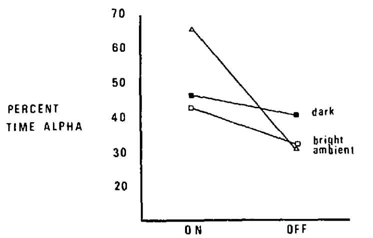

Fig. 3. The interaction between illumination levels and on /off periods.

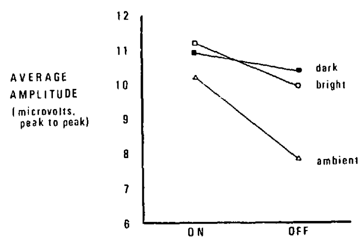

Fig. 4. The interaction between illumination levels and on /off periods.

$\leq$0.01). This suggests that the interactions involving the on /off periods were primarily due to the changes within Group 2.

DISCUSSION

The results of this study indicate that ambient illumination facilitates alpha training, and that the combination of eyes-open, ambient illumination appears to be the optimal condition for alpha training. The effects of eyelid position on alpha training, however, were not as clear. When percent time was utilized as a dependent measure, it appeared that eyes-open training facilitated both alpha enhancement and suppression, while eyes-closed training did not. However, when average amplitude was utilized as a dependent measure, eyelid position did not appear to influence alpha training.

Since this study utilized only binary feedback, eyes-closed training may have been limited because proportional feedback was not used for this training. However, Travis et al. (3) found that eyes-open training facilitated alpha production significantly more than eyes-closed training, regardless of the type of feedback used. While our percent time measure tends to support the efficacy of eyes-open training, this does not appear to be substantiated by the average amplitude measure. It is difficult to interpret such findings. One possibility is that the percent time results are confounded by differences in the amplitudes on which the criterion thresholds were established for these groups. In other words, since the criterion threshold for feedback and percent time data collection was established under "test conditions," the subjects in the eyes-closed condition would have to produce a greater density of alpha at higher absolute levels, as compared to the eyes-open condition, in order to achieve the same fractional increase in the percent time measure during the "on" periods. This would result in percent time differences being due to threshold levels rather than to eyelid position. It should be noted, however, that the subjects in the eyes-closed condition appear to be operating in a restricted range of alpha production when compared to the eyes-open condition. This is suggested in both Figs. 1 and 2.

The findings on ambient illumination

also need further consideration. Since both the percent time and average amplitude measures indicate a significant difference between "on" and "off" periods, the efficacy of this condition for alpha training is strongly supported. The superior performance of this condition for the percent time measure during the "on" periods, however, may again be confounded by the threshold levels. As can be seen in Table 2, both of the groups under ambient illumination had the lowest baseline amplitudes on which their thresholds were set. The other illumination conditions, then, would have to achieve a higher absolute level of alpha production in order to achieve the same fractional increase in the percent time measure during the "on" periods. The average amplitude measure, seen in Fig. 4, indicates no significant differences between illumination conditions during the "on" periods. However, a significant inhibition of alpha production during the "off" periods is indicated for the ambient illumination condition.

The differences between percent time and average amplitude measures are of great interest. Travis et al. (3) found that integrated alpha (average amplitude), as a dependent measure, was more sensitive to their training manipulations than was criterion alpha (percent time alpha). However, in our study, training effects were usually significant using percent time alpha as a dependent measure, while average amplitude reached significance only when the training effects were robust. These discrepant findings more than likely reflect the methods used in determining the criterion threshold values for binary feedback and percent time data collection. The method used in this study was a percent time criterion of between 25% to 35%. Travis et al. (3), on the other hand, used an amplitude criterion (50% of the amplitude of the maximum eyes-closed alpha) to determine their threshold values. Changes in alpha amplitudes, then, may depend on the criterion amplitude used for feedback. The higher the criterion amplitude, the greater the changes in alpha amplitudes as a dependent measure. The suggestion that integrated alpha (or average amplitude) is a way to make it possible to compare results easily between studies needs further consideration.

The effects of illumination levels on alpha enhancement training was first demonstrated by Paskewitz and Orne (9). They found that significant enhancement of alpha production was dependent on procedural conditions (i.e., illumination levels), which initially inhibit alpha densities to a level that is lower than those seen spontaneously under optimal conditions. Some researchers have since hypothesized that eyes-open training results from conditioned disinhibition, and that increasing levels of illumination would further inhibit spontaneous alpha production and thus facilitate such training. The results from this study suggest that such a linear relationship does not exist. The data indicate that no training effects were seen in the bright condition. It may be that the bright illumination levels made it uncomfortable for the subjects to utilize environmental stimuli to inhibit their spontaneous alpha production. If this were the case, one would expect the performance of the bright and dark conditions to be similar. Perhaps the roles of external and internal stimuli in the training of alpha production needs further exploration.

One of the most robust findings in this study is that eyes-open /ambient illumination is the optimal condition for training the control of alpha production. A possible explanation for this finding may lie in the apparent inability for the bright and dark groups to inhibit their alpha production during the "off" periods (see Fig. 4). Although the ambient illumination group indicated significant suppression of their alpha activity (see Fig. 4), a comparison between base-line levels and "on"/"off" levels (Table 2) suggests that there were larger enhancement trends than suppression trends for the eyes open/ambient group. The criticism by Paskewitz and Orne (9) that the enhance/suppress paradigm shows learning because of larger suppression than enhancement trends appears not to be valid, at least from an initial base-line point of view. One might argue that it was a shift in resting alpha baselines and their subsequent suppression that made it possible for the eyes-open/ambient group to show such robust learning effects. Since we could not analyze our rest periods data because of excessive movement artifacts, we cannot address this question directly. However, if this were the case, it is, indeed, an interesting finding that both the bright and dark groups also do not indicate these suppression trends. Perhaps both alpha enhancement and alpha suppression are limited by procedural conditions.

REFERENCES

1. Kamiya J: Operant control of the g alpha rhythm and some of its reported effects on consciousness, in Altered States of Consciousness (edited by C Tart). 1969, pp 480–501.
2. Nowlis D, Kamiya J: The control of EEG alpha rhythm through auditory feedback and the associated mental activity. Psychophysiology 6:476–484, 1970
3. Travis T, Kondo C, Knott J: Parameters of eyes-closed alpha enhancement. Psychophysiology 11:674–681, 1974
4. Black A: The operant conditioning of central nervous system electrical activity, in Biofeedback and Self-Control (edited by DF Shapiro et al.). Aldine Publishing Co., 1973
5. Valle R, Levine L: Expectation effects in alpha wave control. Psychophysiology 12:306–309, 1975
6. Walsh D: Interactive effects of alpha feedback and instructional set on subjective states. Psychophysiology 4:428–435, 1974
7. Kondo C, Travis T, Knott J: The effects of changes in motivation on alpha enhancement. Psychophysiology 12:388–389, 1975
8. Kuhlman W, Klieger D: Alpha enhancement: effectiveness of two feedback contingencies relative to a resting baseline. Psychophysiology 12:456–460, 1975
9. Paskewitz D, Orne M: Visual effects on alpha feedback training. Science 181:360–363, 1973
10. Brown B: Recognition of aspects of consciousness through association with EEG alpha activity. Psychophysiology 6:442–452, 1970
11. Mulholland T, Peper E: Occipital alpha and accomodative vergence, pursuit tracking and fast eye movements. Psychophysiology 8:556–575, 1971